by Subhashish Bhattacharya

MV Power Conversion Systems Enabled by High-Voltage SiC Devices

The current electrical distribution system needs to adapt due to an increase in demand and requirements for a "smarter grid," which are required because of the proliferation of distributed energy resources (DERs). Transformers form an integral part of these electrical grids, and an upgrade to handle the additional requirements that come along is imperative. Unfortunately, an upgrade in a conventional sense is not possible, so it is time to think beyond conventional transformers.

Thanks to recent strides in power electronics research and the availability of high-voltage (HV) silicon carbide (SiC) power semiconductor devices, we can contemplate building a smart "solid-state transformer" to handle the demands of the smart grid. In electrical distribution systems, the transformers convert thousands of volts [medium voltage (MV)] into lower voltages that can be safely used in homes and businesses [1]. With emerging technologies in building and fabricating MV SiC-based power semiconductor devices, MV power conversion on a large-scale scenario seems feasible. While companies, such as Wolfspeed (CREE), General Electric, Infineon Technologies, Mitsubishi, and ROHM, continue to develop and improve these MV semiconductor devices, we at the FREEDM Systems Center are aiming at the application side of things to ensure a market for these power devices.

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We have been working with 15-kV SiC insulated-gate bipolar transistors (IGBTs) and 10-kV SiC MOSFETs to develop solid-state transformers to showcase the viability of a working MV solid-state transformer. In 2010, the U.S. Department of Energy's (DOE's) Advanced Research Projects Agency-Energy (ARPA-E) awarded our team US$4.2 million to build a three-phase solid-state transformer from the 15-kV SiC IGBTs. The project was called the *Transformerless Intelligent Power Substation* (*TIPS*) [2].

With the TIPS project, a successful demonstration of MV SST was carried out for the first time using these SiC devices. Several technical questions related to the viability of such an approach were answered. It was proven

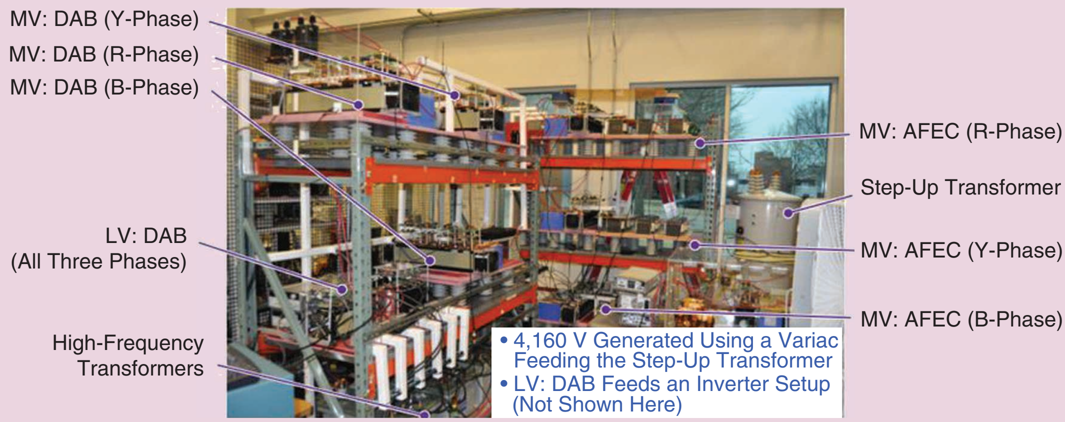

FIG 1 An experimental setup of the TIPS system at the North Carolina State University (NCSU) FREEDM System Center.

that a paradigm shift is required in the design approach for the MV SiC-based converter as compared to the Si-based converter systems. In addition to the power semiconductor device design, the auxiliary systems like gate drivers, magnetics, grounding schemes, and so on play a very important role in the successful operation of MV converter systems. The TIPS system also proved that it is time to invest in novel magnetic material, design, and architecture if SiC-based systems are to take over the current Si-based systems.

It should be noted that the TIPS system can be broadly divided into three major power conversion systems: MV ac–dc conversion [MV: Active Front-End Converter (AFEC)], MV dc-LV dc [Dual Active Bridge Converter (DAB)], and LV ac–dc conversion (LV: AFEC) as shown in Figure 1. For a solid-state transformer, all of these converters need to work in sync. Applications

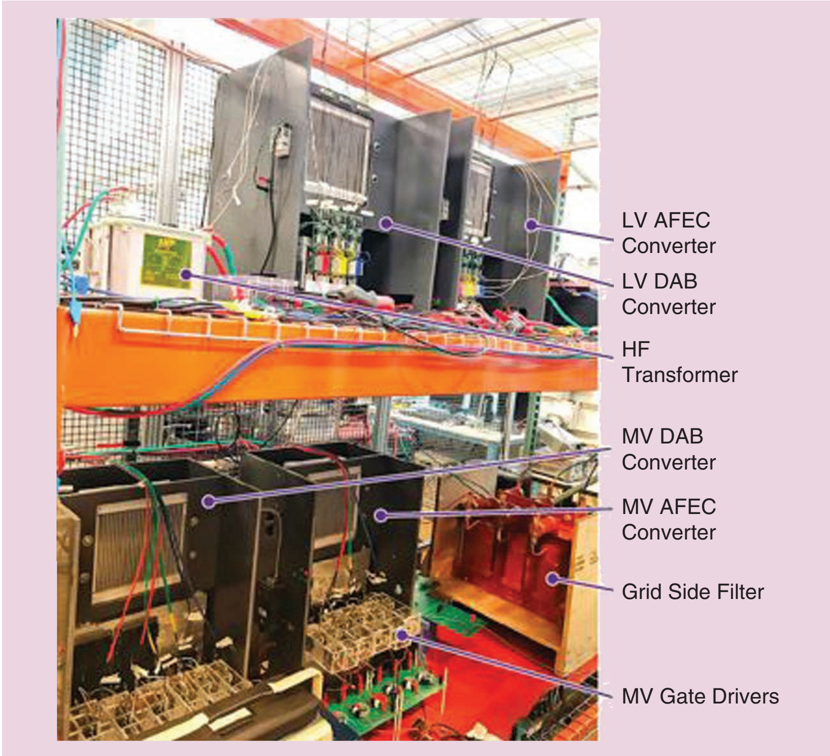

FIG 2 Experimental setup of the MUSE-SST system at NCSU's FREEDM System Center.

involving a single conversion state can still be carried out by one of the converter systems.

While the TIPS system is aimed at a solid-state transformer application, it involves MV ac–dc or dc–ac, and MV dc–dc conversion stages that validates the use of SiC devices for most of the applications when used separately. For example, the dc–ac conversion stage enables high-speed MV motor drive applications, which was not possible before using Si technology.

In 2016, ONR-SPAWAR funded our team so that we could build a 100-kW solid-state transformer based on Wolfspeed's 10-kV SiC MOSFETs. This transformer is called the *Mobile Utility Support Equipment-Based Solid-State Transformer* (*MUSE-SST*). MUSE-SST is aimed at integrating a MV 4160-V grid to an LV 480-V grid as shown in Figure 2 [3]. While the overall aim of MUSE-SST is like that of TIPS, the project aims at validating the new generation of MV SiC MOSFETs. The use of MV SiC MOSFETs over MV SiC IGBTs enables a higher switching frequency operation. While the TIPS system operates at 5 kHz (MV: AFEC) and 10 kHz (DAB), the MUSE-SST system operates at 10 kHz (MV: AFEC) and 20 kHz (DAB) while maintaining a similar efficiency.

With the 10-kV SiC MOSFETs being the most mature MV power semiconductor device technology available, the use of multilevel topologies is required to aim for higher voltage applications. Also, a series connection of the power semiconductor devices is being investigated for blocking 22 kV for a solid-state transformer application to integrate two 13.8-kV grids [4]. The use of active gating techniques or snubber circuits ensure voltage balancing between the MV power devices.

While the MV SiC devices brings in a lot of advantages and opens new areas of application, it does come with its own cost. While these devices are extremely expensive as of now, due to its nascent stage of development, it is necessary that these should be inexpensive enough to make using these devices feasible. In addition, the converter design needs very special and careful consideration to account for the high blocking voltage and the high rate of change of voltage across the semiconductor device [5]. Also, if we discuss replacing the conventional transformers with solid-state ones, its resistance to extreme weather conditions must be considered. Semiconductor devices are less forgiving than passive magnetic components when it comes to abnormal operating conditions. These devices are susceptible to faults and have reliability issues as compared to conventional transformers.

While most of the technology is new, the concept of building converter systems from MV power semiconductor devices is fascinating. At FREEDM Systems Center, we envisage that our research will pave the way for wider growth of these MV devices and accelerate their deployment in real field operations.

About the Author

Subhashish Bhattacharya (sbhatta4@ncsu.edu) received his B.E. degree from the Indian Institute of Technology, Roorkee, in 1986; his M.E. degree from the Indian Institute of Science, Bengaluru, in 1988; and his Ph.D. degree from the University of Wisconsin–Madison in 2003, all in electrical engineering. He was with the Flexible AC Transmission Systems and Power Quality Division, Westinghouse/Siemens Power Transmission and Distribution from 1998 to 2005. In August 2005, he joined the Department of Electrical and Computer Engineering, North Carolina State University, Raleigh, where he is currently the Duke Energy Distinguished Professor in Electrical and Computer Engineering and a founding faculty member of the National Science Foundation's FREEDM Systems Center and the U.S. Department of Energy PowerAmerica Institute. A portion of his Ph.D. research on active power filters was commercialized by York Corporation for air conditioner chillers. His research interests include solid-state transformers, medium-voltage power converters, FACTS, utility applications, high-frequency magnetics, and power-conversion applications of silicon-carbide devices. He is a Senior Member of the IEEE.

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